

PROCESS FOR PRODUCING CARBONIZED PRODUCT USED  
FOR PRODUCING ACTIVATED CARBON FOR ELECTRODE  
OF ELECTRIC DOUBLE-LAYER CAPACITOR, AND  
ORGANIC MATERIAL FOR CARBONIZED PRODUCT

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a process for producing a carbonized product used for producing activated carbon for an electrode of an electric double-layer capacitor, and to an organic material for the carbonized product.

DESCRIPTION OF THE RELATED ART

There is such a known process for producing a carbonized product, in which a mesophase pitch having an optical anisotropic rate  $O_a$  equal to 100 % is subjected to a thermal treatment and then to carbonizing treatment, or subjected to an insolubilizing treatment and then to a carbonizing treatment (for example, see Japanese Patent application Laid-open No.2002-93667, [0018] to [0020] and Table 1).

However, the activated carbon for the electrode produced using the carbonized product in the above-described conventional process suffers from a problem that its electrostatic capacity density (F/cc) varies widely, and it is difficult to stably produce activated carbon for an electrode having a high electrostatic capacity density (F/cc).

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to

provide a process for producing a carbonized product which makes it possible to stably produce activated carbon having a high electrostatic capacity density (F/cc) by subjecting a particular organic material for the carbonized product or by performing a particular carbonizing treatment.

To achieve the above object, according to the present invention, there is provided a process for producing a carbonized product used for producing activated carbon for an electrode of an electric double-layer capacitor, comprising the steps of subjecting a condensed polycyclic aromatic pitch having an optical anisotropic rate  $O_a$  in a range of  $1\% \leq O_a \leq 90\%$  and a softening point  $T_s$  in a range of  $140^\circ\text{C} \leq T_s \leq 260^\circ\text{C}$  to an oxygen crosslinking treatment at a heating temperature  $T_h$  set at  $T_h < 260^\circ\text{C}$  to provide an organic material for a carbonized product having a light component content  $L$  equal to or larger than  $14.5\%$  by weight, and subjecting the organic material to a carbonizing treatment at a temperature-raising rate  $R_t$  set at  $R_t \geq 500^\circ\text{C}/\text{h}$  and at a heating temperature  $T_h$  set in a range  $600^\circ\text{C} \leq T_h \leq 1,000^\circ\text{C}$  for a heating time  $t$  set at  $t \leq 2$  hr.

A condensed polycyclic aromatic pitch having a low softening point  $T_s$  as described above has an undeveloped optical anisotropic phase and a relatively small average molecular weight, and has a relatively large content of light components (components having low boiling points). An organic material produced by subjecting the condensed polycyclic aromatic pitch to an oxygen crosslinking treatment at the above-described heating temperature  $T_h$ , has a

characteristic that the intrinsic object of the oxygen crosslinking treatment can be achieved, and the development of graphitization in the carbonizing treatment can be suppressed. In addition, at the heating temperature  $T_h$  the advance of the dehydrogenation of light components and naphthene ring contained in the condensed polycyclic aromatic pitch is also suppressed, so that a non-mesophase state of the pitch is maintained.

However, when a condensed polycyclic aromatic pitch having a softening point  $T_s$  lower than  $140^{\circ}\text{C}$  or higher than  $260^{\circ}\text{C}$  is used, it is impossible to eventually produce an excellent activated carbon. This also applies to a case where the light component content  $L$  is lower than 14.5 % by weight. Also, when the heating temperature  $T_h$  is equal to or higher than  $260^{\circ}\text{C}$ , the dehydrogenation advances and as a result, the characteristic of the condensed polycyclic aromatic pitch is lost.

When such an organic material is subjected to a carbonizing treatment at a high temperature-raising rate at a high temperature for a short time, the dehydrogenating reaction of the light components and the naphthene ring can be caused to hinder the advance of mesophasing and to form a large number of fine pores. The condensed polycyclic aromatic pitch has an undeveloped optical anisotropic phase and a relatively small average molecular weight, so that the condensation reaction of the organic ring caused by the carbonizing treatment is small, and the molecular weight is not increased. Further, the development of carbon crystallites is uniform, whereby a carbonized product having a high density

can be produced.

However, when the temperature-raising rate  $R_t$  is lower than  $500^{\circ}\text{C/hr}$ , the mesophasing of the organic material advances. When the heating temperature  $T_h$  is lower than  $600^{\circ}\text{C}$ , a sufficient carbonizing treatment cannot be conducted, and when the heating temperature  $T_h$  is higher than  $1,000^{\circ}\text{C}$ , an alkali activating treatment after the carbonizing treatment does not advance. Further, when the heating time  $t$  is shorter than 2 hours, a sufficient carbonizing treatment cannot be conducted, and when the heating time  $t$  is longer than 2 hours, the dehydrogenation excessively advances, so that the contraction of particles of the carbonized product occurs to cause the disappearance of fine pores.

When the carbonized product is subjected to an alkali activating treatment, the fine pores are uniformly widened, to thereby stably produce an activated carbon for an electrode having a high electrostatic capacity density (F/cc).

The above and other objects, features and advantages of the invention will become apparent from the following description of the preferred embodiment taken in conjunction with the accompanying drawing.

#### BRIEF DESCRIPTION OF THE DRAWING

Fig.1 is a broken-away front view of essential portions of a button-shaped electric double-layer capacitor.

### DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention will now be described by way of a preferred embodiment with reference to the accompanying drawings.

Referring first to Fig.1, a button-shaped electric double-layer capacitor 1 includes a case 2, a pair of polarized electrodes 3 and 4 accommodated in the case, a spacer 5 interposed between the polarized electrodes 3 and 4, and an electrolytic solution charged into the case 2. The case 2 comprises a body 7 made of aluminum and having an opening 6, and a lid plate 8 made of aluminum and closing the opening 6. A space between an outer periphery of the lid plate 8 and an inner periphery of the body 7 is sealed by a seal material 9. Each of the polarized electrodes 3 and 4 is formed of a mixture of activated carbon for the electrode, a conductive filler and a binder.

The activated carbon for the electrode is produced by sequentially carrying out: a step of subjecting a starting carbon material to an oxygen crosslinking treatment to provide an organic material for a carbonized product; a step of subjecting the organic material to a carbonizing treatment to provide a carbonized product; a step of subjecting the carbonized product to a pulverizing treatment; a step of subjecting the pulverized carbonized product to an alkali activating treatment; and steps of washing, filtering and drying treatments to provide an activated carbon.

Used as the starting carbon material is a condensed polycyclic aromatic pitch which is a graphitizing carbon material

and which has a softening point  $T_s$  in a range of  $140^{\circ}\text{C} \leq T_s \leq 260^{\circ}\text{C}$ . The condensed polycyclic aromatic pitch has an optical anisotropy rate  $O_s$  in a range of  $1\% \leq O_s \leq 90\%$ , preferably  $O_a < 50\%$ . If the optical anisotropy rate  $O_s$  is deviated from this requirement, it is not preferred for increasing the electrostatic capacity density (F/cc) of the activated carbon for the electrode. The condensed polycyclic aromatic pitch may be a chemically synthesized pitch, or a pitch produced from a petroleum pitch or a coal pitch. However, the pitch produced from the petroleum pitch and the like contains impurities in a content of 1,000 ppm or more. The impurities include large amounts of N and S, and other metal impurities such as Al, Si, V, Mg, Na and Ca. The increased amount of the impurities is not preferred, because they exhibit activating points during the alkali activating treatment to affect the distribution of pores in the activated carbon for the electrode after the activation, or they remain in the activated carbon for the electrode to react, thereby causing a reduction in capacity of the electric double-layer capacitor, generation of gas, an increase in resistance and the like. It is preferable that the amount of the impurities, excepting C, O, H and S, is equal to or smaller than 100 ppm. To pulverize the starting carbon material, a ball mill, a jet mill, a high-speed rotary mill or the like is used.

The oxygen crosslinking treatment is carried out to crosslink together benzene rings of the adjacent condensed polycyclic organic compounds via oxygen in the condensed

polycyclic aromatic pitch. An element ratio H/C of the organic material produced by the oxygen crosslinking treatment is larger than 0.38, desirably, equal to or larger than 0.63 ( $H/C \geq 0.68$ ). In this case, the organic material has a high element ratio H/C and causes a melt foaming, and a so-called insolubilizing effect is not provided by the oxygen crosslinking treatment, but it is possible to provide such an activating effect that the interlaminar distance  $d_{002}$  between carbon crystallites is increased by the oxygen crosslinking treatment to enhance the permeability to KOH.

An oxygen crosslinking rate  $D_L$  is varied depending on the molecular structure of the starting carbon material, and is represented by  $DL = [1 + \{(W_2 - W_1)/W_1\}] \times 100$  (%), wherein  $W_1$  represents a weight of the condensed polycyclic aromatic pitch before being oxygen-crosslinked, and  $W_2$  represents a weight of the organic material. The oxygen crosslinking rate  $D_L$  is set in a range of  $100.01 \% \leq DL \leq 106 \%$ . In this case, even if the treatment is carried out at an oxygen crosslinking rate as low as  $D_L$  equal to 100.01 %, effects of decreasing the activation variation and the resistance of the electric double-layer capacitor are provided. However, if  $D_L < 100.01 \%$ , the meaning of carrying out the oxygen crosslinking is lost. On the other hand, if  $D_L > 106 \%$ , a reduction in productivity of the activated carbon for the electrode is brought about. To achieve the oxygen crosslinking rate  $D_L$  in the above-described range, the crosslinking treatment is carried out in an oxygen current at a heating temperature  $T_h$  set in a range of  $150^\circ\text{C} \leq T_h < 260^\circ\text{C}$  for a heating time  $t$  set in a range of  $10^{-3}$

$\text{hr} \leq t \leq 10 \text{ hr}$ . The heating temperature  $T_h$  is determined based on the softening point  $T_s$  of the starting carbon material. The oxygen crosslinking treatment may be carried out at a single stage or at a plurality of stages. A high-molecular weight substance produced from  $\text{P}_2\text{O}_5$ , quinone, hydroquinone and a hydroquinone derivative, and  $\text{NO}_2$  may be used as the crosslinking agent.

The carbonizing treatment is carried out in an inert gas at a heating temperature  $T_h$  set in a range of  $500^\circ\text{C} \leq T_h \leq 1,000^\circ\text{C}$  for a heating time  $t$  set at  $t \leq 2 \text{ hr}$ . In this case, especially, a dehydrogenating reaction of a light component and a naphthene ring is caused by increasing the temperature-raising rate in the process of raising temperature and by conducting the carbonizing treatment at a high temperature for a short time, thereby hindering the advance of the mesophasing and forming a large number of fine pores. The organic material and thus the condensed polycyclic aromatic pitch has an undeveloped optical anisotropic phase and a relative small average molecular weight, so that the condensation reaction of an organic ring caused by the carbonizing treatment is small, and the molecular weight is not increased and further, the development of carbon crystallites is uniform. Thus, a carbonized product having a high density can be produced. The temperature-raising rate  $R_t$  is set at  $R_t \geq 500^\circ\text{C/hr}$ , preferably,  $R_t \geq 700^\circ\text{C/hr}$ .

In the carbonized product produced by the carbonizing treatment, an interlaminar distance  $d_{002}$  between the carbon crystallites is in a range of  $3.40 \text{ nm} \leq d_{002} \leq 0.350 \text{ nm}$ , and a true



density  $d$  is in a range of  $1.3 \text{ g/cc} \leq d \leq 2.0 \text{ g/cc}$ . Further, an element ratio  $H/C$  is in a range of  $0.1 \leq H/C \leq 0.35$ .

In the pulverizing treatment, a pulverizer such as a ball mill, a jet mill, a high-speed rotary mill or the like is used. The particle size of the powdery carbonized product is set in a range of  $1 \text{ }\mu\text{m} \leq D_m \leq 50 \text{ }\mu\text{m}$  in terms of a median diameter  $D_m$ . The efficiency of the alkali activating treatment can be enhanced by carrying out such particle-size regularization.

KOH is used as a treating agent in the alkali activating treatment for the powdery carbonized product, which is carried out in an inert gas atmosphere at a heating temperature  $T_h$  set in a range of  $500^\circ\text{C} \leq T_h < 900^\circ\text{C}$  for a treating time  $t$  set in a range of  $10^{-3} \text{ hr} \leq t \leq 10 \text{ hr}$ . In the alkali activating treatment, a heating treatment may be carried out at a heating temperature  $T_h$  set in a range of  $400^\circ\text{C} \leq T_h < 450^\circ\text{C}$  for a treating time  $t$  set in a range of  $10^{-1} \text{ hr} \leq t \leq 10 \text{ hr}$  for the purpose of dehydration at a preliminary stage. Thus, an activated carbon having a specific surface area of  $800 \text{ m}^2$  or less measured by a nitrogen gas adsorption process and a pore volume of  $0.25 \text{ cc/g}$  or less is produced.

Specific examples will be described below.

(Starting carbon material)

Table 1 shows the optical anisotropic rate  $O_a$  and the softening point  $T_s$  in examples (1) to (5) of condensed polycyclic aromatic pitches and a commercially available mesophase pitch.

Table 1

Starting carbon material	Optical anisotropic rate Oa (%)	Softening point Ts (°C)
Example (1)	4	170
Example (2)	8	190
Example (3)	49	220
Example (4)	90	260
Example (5)	100	285
Example (6): Commercially available pitch	75	290

In Table 1, each of the examples (1) to (5) is a chemically synthesized pitch, while the commercially available pitch is a pitch produced from a petroleum pitch and manufactured under a trade name of MPM-BO by Advanced Chemicals Corporation. The optical anisotropic rate Oa was determined as follows: each of the examples (1) to (6) was shot under a crossed nicol by a polarization microscope; and an area rate of an optical anisotropic phase of the sample in the photograph was calculated and determined as an optical anisotropic rate Oa.

(Production of activated carbon for electrode)

(a) A starting massive carbon material comprising 10 g of the example (1) was pulverized by a laboratory cutter mill to provide a powdery carbon material having an average particle size of about 0.5 mm. (b) The powdery carbon material was spread on an upper surface of a retaining plate within an oven so that it readily contacts oxygen. Then, air was supplied at 10 L/min into the oven, and the powdery carbon material was subjected to an oxygen

crosslinking treatment at a temperature-raising rate of  $1^{\circ}\text{C}/\text{min}$ , and it was retained at  $130^{\circ}\text{C}$  for 3 hours and at  $170^{\circ}\text{C}$  for 3 hours, thereby providing a powdery organic material. Thereafter, an oxygen crosslinking rate  $D_L$  was determined for the powder organic material, resulting in  $D_L$  equal to 100.05 %. (c) The powdery organic material was placed into a carbonizing furnace, where it was subjected to a carbonizing treatment in a nitrogen gas current at a temperature-raising rate of  $900^{\circ}\text{C}/\text{hr}$  and it was retained at  $700^{\circ}\text{C}$  for 1 hour, thereby providing a carbonized product. (d) The carbonized product was subjected to a pulverizing treatment using a laboratory cutter mill to provide a powdery carbonized product having a median diameter  $D_m$  equal to  $21\text{ }\mu\text{m}$ . (e) 2.5 grams of the carbonized product and an amount of KOH pellet having a weight twice of that of the carbonized product and a purity of 95 %, were mixed together sufficiently, and the mixture was then charged into a boat made of Ni. (f) The boat was placed into a tubular furnace, where it was heated at a temperature-raising rate of  $200^{\circ}\text{C}/\text{hr}$ , and retained at  $450^{\circ}\text{C}$  for 3 hours and then at  $800^{\circ}\text{C}$  for 3 hours. Next, the boat was taken out of the tubular furnace, and the treated powder was subjected to HCl washing and warm water washing to remove KOH therefrom, and to the filtration and drying to provide an activated carbon for an electrode having an average particle size of  $15\text{ }\mu\text{m}$ . The activated carbon for the electrode made in this manner is referred to as the example (1) for convenience.

Examples (2) to (5) and an example (6) of the activated

carbons for an electrode were produced in the same manner, using starting massive carbon materials each comprising the examples (2) to (5) and the commercially available pitch. The examples (2) to (5) and the example (6) correspond to the examples (2) to (5) and the commercially available pitch of starting carbon materials, respectively.

Using starting massive carbon materials comprising the examples (2) and (4) were used as examples (2<sub>1</sub>) and (4<sub>1</sub>), examples (2<sub>1</sub>) and (4<sub>1</sub>) of the activated carbons for electrodes corresponding to the examples (2<sub>1</sub>) and (4<sub>1</sub>) were produced in the same manner, except that the oxygen crosslinking treatment was carried out at the temperature-raising rate of 2°C/min, and the examples were retained at 250°C for 3 hours and then at 300°C for 3 hours.

Table 2 shows the oxygen crosslinking treatment conditions and oxygen crosslinking rate  $D_L$  for the examples (1) to (5) of the starting carbon material, the example (6) of the commercially available mesophase pitch, and the examples (2<sub>1</sub>) and (4<sub>1</sub>).

Table 2

Starting carbon material	Oxygen crosslinking treatment	
	Conditions	Oxygen crosslinking rate $D_L$ (%)
Example (1)	1°C/min	100.05
Example (2)	140°C for 3 hours	100.11
Example (3)	170°C for 3 hours	100.20
Example (4)		100.25
Example (5)		100.25
Example (6): Commercially available pitch		100.15
Example (2 <sub>1</sub> )	2°C/min	106.4
	250°C for 3 hours	
Example (4 <sub>1</sub> )	300°C for 3 hours	106.5

Table 3 shows the element ratio H/C of the organic material and the carbonized product, the rate  $W_c$  of change in weight due to the dehydrogenation, the carbonization yield  $C_y$  and the content  $L$  of light components in the organic material for the oxygen crosslinking treatment for the examples (1) to (5) of the starting carbon material, the example (6) of the commercially available mesophase pitch, and the examples (2<sub>1</sub>) and (4<sub>1</sub>).

Table 3

Starting carbon material	H/C		Rate Wc of change in weight (% by weight)	Carbonization yield Cy (wt %)	Content L of light components in organic material (wt %)
	Organic substance	Carbonized product			
Example (1)	0.73	0.23	96.1	70	26.1
Example (2)	0.73	0.23	96.1	73	23.1
Example (3)	0.67	0.21	96.4	80	16.4
Example (4)	0.65	0.21	96.5	82	14.5
Example (5)	0.63	0.21	96.7	86	10.7
Example (6): Commercially available pitch	0.38	0.20	98.5	90	8.5
Example (2 <sub>1</sub> )	0.73	0.23	96.1	84	12.4
Example (4 <sub>1</sub> )	0.65	0.21	96.5	85	11.5

The element ratio H/C was determined in the following manner: a specimen sampled from the example (1) or the like was subjected to a vacuum drying treatment at a temperature lower than its melting point for 3 hours; then, about 1.5 mg of the specimen was then subjected to the analysis of H and C using CHN coder MT-5 type analyzer manufactured by Yanagimoto; and about 3 mg of the specimen was subjected to the analysis of O using a CHN coder MT-3 type analyzer manufactured by Yanagimoto.  $N = 2$  or more at the time when the result of the analysis reached  $C + H + O > 98 \%$ , was adopted as data.

The rate  $W_c$  of change in weight was determined in the following manner: For example, in the example (1), because the element ratio H/C of the organic material is equal to 0.73, the weight ratio H/C is represented by  $H/C = (0.73 \times 1)/(1 \times 12) = 0.73/12$ , and the weight H+C of the organic material is equal to 12.73 g. On the other hand, because the element ratio H/C of the carbonized product is equal to 0.23, the weight ratio H+C is represented by  $H/C = (0.23 \times 1)/(1 \times 12) = 0.23/12$ , and the weight of the carbonized product is equal to 12.23 g. The rate  $W_c$  of change in weight is represented by  $W_c = (12.23/12.73) \times 100 \approx 96.1 \%$  by weight. In this case, the carbonization yield  $C_y$  is 70 % by weight, and the content L of light components in the organic material is represented by  $L = 96.1 - 70 = 26.1 \%$  by weight, because the carbonization yield  $C_y$  is determined

according to  $Cy = (W_3/W_2) \times 100$  (%) from the weight  $W_2$  of the organic material and the weight  $W_3$  of the carbonized product.  
(Production of button-shaped electric double-layer capacitor)

The example (1) of the activated carbon for the electrode, a graphite powder (a conductive filler) and PTFE (a binder) were weighed so that a weight ratio was 90 : 5 : 5. Then, the weighed materials were kneaded together and then subjected to a rolling to fabricate an electrode sheet having a thickness of 185  $\mu\text{m}$ . Two polarized electrodes each having a diameter of 20 mm were cut off from the electrode sheet, and a button-shaped electric double-layer capacitor 1 shown in Fig.1 was fabricated using the two polarized electrodes, a spacer 5 made of PTFE and having a diameter of 20 mm and a thickness of 75  $\mu\text{m}$ , an electrolytic solution and the like. A solution of 1.8 M triethylmethyl ammonium tetrafluoroborate  $[(\text{C}_2\text{H}_5)_3\text{CH}_3\text{NBF}_4]$  in propylene carbonate was used as the electrolytic solution. Seven button-shaped electric double-layer capacitors were fabricated in the same process using the examples (2) to (6), (2<sub>1</sub>) and (4<sub>1</sub>).

[Electrostatic capacity density (F/cc) of activated carbon for electrode]

Each of the electric double-layer capacitors was subjected to a charging/discharging cycle which will be described below, and an electrostatic capacity density (F/cc) per unit volume of each of the electric double-layer capacitors



was then determined in an energy conversion method. In the charging/discharging cycle, a process comprising charging for 90 minutes and discharging for 90 minutes was conducted once at 27 V, once at 2.8 V and once at 2.7 V.

Table 4 shows the electrode density and the electrostatic capacity density (F/cc) at 2.7 V for the examples (1) to (4<sub>1</sub>) of the activated carbon for the electrode.

Table 4

Activated carbon of electrode	Starting carbon material	Electrode density (g/cc)	Electrostatic capacity density (F/cc)
Example (1)	Example (1)	1.07	41.7
Example (2)	Example (2)	0.95	38.1
Example (3)	Example (3)	1.06	37.5
Example (4)	Example (4)	1.06	36.0
Example (5)	Example (5)	0.90	32.5
Example (6)	Example (6): Commercially available mesophase carbon	0.88	31.0
Example (2 <sub>1</sub> )	Example (2 <sub>1</sub> )	1.13	28.6
Example (4 <sub>1</sub> )	Example (4 <sub>1</sub> )	0.88	32.5

As apparent from Tables 1 to 4, the activated carbon for the electrode having a high electrostatic capacity density (F/cc) at a low voltage can be produced, if the carbonized product is used which is produced as follows: each of the examples (1) to (4) of the condensed polycyclic aromatic pitches having an optical anisotropic rate  $O_a$  in a range of  $1 \% \leq O_a$

$\leq 90 \%$  and a softening point  $T_s$  in a range of  $140^\circ\text{C} \leq T_s \leq 260^\circ\text{C}$  is subjected to the oxygen crosslinking treatment at a heating temperature  $T_h$  set at  $T_h < 260^\circ\text{C}$  to thereby provide the organic material having a content  $L$  of light components equal to or larger than  $14.5 \%$  by weight; and the organic material is subjected to the carbonizing treatment at a temperature-raising rate  $R_t$  set at  $R_t \geq 500^\circ\text{C/hr}$  at a heating temperature  $T_h$  set in a range of  $600^\circ\text{C} \leq T_h \leq 1,000^\circ\text{C}$  for a heating time  $t$  set at  $t \leq 2$  hr. The electrostatic capacity density of each of the examples (5) and (6) of the activated carbon for the electrode is lower as compared with the examples (1) to (4), because the softening point  $T_s$  of the condensed polycyclic aromatic pitch is higher than  $260^\circ\text{C}$  in the case of the example (5) of the activated carbon for the electrode and because the commercially available mesophase pitch is used as the starting carbon material in the case of the example (6) of the activated carbon for the electrode. Further, even when the examples (2<sub>1</sub>) and (4<sub>1</sub>) of the condensed polycyclic aromatic pitches having the lower softening point  $T_s$  as in the case of the examples (2<sub>1</sub>) and (4<sub>1</sub>) of the activated carbons for the electrodes are used, if the heating temperature  $T_h$  in the oxygen crosslinking treatment is set at  $T_h > 260^\circ\text{C}$ , the electrostatic capacity density (F/cc) is low as compared with the examples (2) and (4) of the activated carbons for the electrodes.

If the examples (1) to (3) of the activated carbons for the electrodes are compared with the example (4) of the activated carbon for the electrode, it is considered that a condensed polycyclic aromatic pitch having an optical anisotropic rate  $O_a$  smaller than 50 % is preferred to a condensed polycyclic aromatic pitch having an optical anisotropic rate  $O_a$  equal to or larger than 50 %, in order to enhance the electrostatic capacity density (F/cc).